Vegetation Monitoring Protocol for Klamath Network Parks

Standard Operating Procedure (SOP) #12: Reporting and Analysis of Data

Version 1.00

Revision History Log:

Previous Version	Revision Date	Author	Changes Made	Reason for Change	New Version

This SOP details the reporting and analysis components of the vegetation monitoring protocol. There are two main elements: (1) Annual reports and (2) third year Analysis and Synthesis reports. These reports will be authored by the Project Lead with assistance from the Data Manager and possibly interested university or USGS collaborators. The audience for the reports includes superintendents, resource managers, Klamath Network staff, service-wide program managers, external scientists, and partners. The reports are intended to address specific objectives of the vegetation monitoring protocol developed by the Klamath Network, as shown in Table 1, as well as the specific purposes of the reports, as discussed below.

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Table 1. Overview of general reporting tools with purpose/objectives and reporting year.

Report	Year	Objective					
		Status and trends in vegetation composition	Status and trends in vegetation composition, structure, and function: Implications for fire.	Status and trends in vegetation structure, and function: Implications for wildlife	Status and trends in vegetation structure, and function: stand dynamics ddynamicsdddDddynamics.	Have the sensitivity to detect significant non-linear shifts in vegetation and a 50 percent gradual change in vegetation should they occur with approximately 80 percent power.	Provide data for modeling invasive species distributions.
Annual Report <u>Purposes</u> • Summarize annual data and monitoring activities • Describe current year's sampling (vegetation status) • Document changes in monitoring protocols • Increase communication between the parks and the I&M Program	All sampling years	X	X		X		X
Analysis and Synthesis Reports <u>Purposes</u> • Determine patterns/trends in vegetation • Discover new characteristics of resources and correlations among resources being monitored • Analyze data to determine amount of change that can be detected by the type and level of sampling • Recommend changes to management of resources	Every three years	↓	↓	↓	↓	↓	↓
Analysis and Synthesis Report 1: Vegetation Composition	2013	X					X
Analysis and Synthesis Report 2: Vegetation Composition, Structure and Function: Interactions with fire	2016				X		
Analysis and Synthesis Report 3: Vegetation Structure and Function: Wildlife Habitat	2019		X				
Analysis and Synthesis Report 4: Stand Dynamics	2022	X	X		X	X	
Analysis and Synthesis Report 5—Vegetation Status and Trends for all Parks	2025	X	X		X	X	

Approach to Data Analysis

Appendix A, which summarizes data from the pilot study, provides a starting point for the reporting the Network will provide on an annual basis. However, at this point, without a full year's sampling data from the protocol, the spatial and temporal variance structure and other aspects of the data that will be acquired in the future are impossible to know. Therefore, it is not possible to precisely prescribe all the specific data analyses that will be conducted. Moreover, some methods are evolving quickly, particularly multivariate analyses using species and environmental data. Accordingly, the Network will continue to work with statisticians to help standardize data analysis methods. In addition, the initial version of each report described below will establish standards and a template for later reports of the same kind. A key requirement for this protocol is that the Project Lead is a scientist possessing strong skills in analyzing multivariate vegetation data and knowledge of the literature on this topic.

Annual Reports

The purposes of annual reports are listed in Table 1. Each of these reports will focus on the status of the two parks sampled in the previous field season. Annual reports will be due to park managers and other interested parties and recipients on March 1st. Appendix A is an example annual report based on the pilot study data. It is intended to be used as a template for future reports. As illustrated in Appendix A, Annual reports will summarize the previous year's monitoring activities and data collected. However, unlike the sample report in Appendix A, actual Annual reports will discuss vegetation status and trends (pilot study data were too limited for this). After initial screening and quality control, data will be presented using summary statistics (range, mean, median, standard deviation) and user-friendly graphics (e.g., bubble maps, histograms, and tables) (Appendix A). The data will also be transformed where necessary and possible, to meet the normality assumptions for any parametric statistics employed to link vegetation and environment variables. Standard techniques for evaluating and transforming statistical distributions will be used (histograms, Q-Q plots) (Zar 1999, Legendre et al. 2002). For detecting effects of environmental factors (e.g., elevation, slope, aspect, and topographic position of plots) on vegetation parameters, correlation matrices between variables and vegetation parameters will be prepared as shown by example in Appendix A. Interactive effects among environmental variables and vegetation parameters may be explored using multiple regression approaches to identify the most parsimonious predictive model relating a combination of environmental variables and vegetation parameters. The Project Lead will determine specific analyses in consultation with statisticians, as needed. Any unusual or special significance findings (e.g., new species documented for a park) will also be highlighted in Annual reports. Invasive species distribution and abundance will be summarized, and the usefulness of the data for modeling invasives (protocol objective 6) will be discussed. However, any invasive species modeling analyses will be reported fully under the Klamath Network Invasive Species Protocol.

A section of the Annual report will be devoted to describing any changes to the specific instructions in the protocol that were suggested by the field crew and Project Lead as a result of implementing the protocol the previous season. If necessary, specific protocol revisions will be proposed for formal consideration. The first annual report will replace Appendix A as the template for future annual reports, and the data analyses described in the preceding paragraph will likely be updated.

Analysis and Synthesis Reports

Analysis and Synthesis reports will be prepared every 3 years after a complete sampling cycle of all panels of plots in the six parks of the Network. These reports will distributed by May 1st of each year shown in Table 1. The four purposes of Analysis and Synthesis reports as listed in

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Table 1, from Sarr et al. (2007), are addressed in the series of reports described below. These reports will also highlight similarities and contrasts among the parks as well as explore emergent, network-wide patterns.

Analysis and Synthesis Report 1: Vegetation Composition

Once data have been collected from each park, Analysis and Synthesis Report 1 will describe vegetation status, focusing on vascular plant species composition and richness patterns in the Network. Structure and function data from annual reports will also be summarized at the Network level. The specific parameters to be analyzed, vegetation composition sub-objectives, and methods of data analysis are described in Table 2. The spatial variability of vegetation parameters (i.e., variance structure of the data) captured by the sample frame will be analyzed for its ability to describe vegetation status for each park. Vegetation and environmental data will be co-analyzed to best explain fundamental vegetation and environmental relationships in the parks.

In order to describe status in vegetation composition, an analysis that provides a synthetic understanding of the natural variation in species assemblages across the gradients in park ecosystems will be needed (Whittaker 1967). The vegetation composition and environmental data will be particularly well suited for analyses of species assemblages across gradients in park ecosystems. The presence/absence of species, and their cover, will be analyzed together with environmental data using ordination and classification techniques for community composition data, such as Non-Metric Multidimensional Scaling and constrained ordinations (Kruskal 1964, McCune and Grace 2002). These techniques will illustrate interrelationships among species assemblages at sites and parks and will be invaluable for distinguishing spatial from temporal variation in subsequent trend detection analyses (Philippi et al. 1998), discussed below under Analysis and Synthesis Report 5.

Table 2. Compositional parameters to be analyzed in Analysis and Synthesis Report 1 and the types of analyses and covariables to be examined.

Parameter	Vegetation Composition Sub-objective	Suggested Analyses and Software
Species cover and frequency	Describe vegetation composition and diversity in each park sample frame	Calculate species richness, species/area relationships, evenness, and heterogeneity (pairwise mean dissimilarity across all sites) for each sample frame using presence/absence data. Software: PC-Ord, PRIMER
Species cover or frequency	Describe vegetation distribution in relation to environment.	Nonmetric Multidimensional Scaling and constrained (Canonical Analysis of principle coordinates) ordinations (Sørensen distance measure) for each sampling frame and all samples in the park. Use cover data with 100 percent cover maxima for species whose cover in all strata sums to more than 100 percent. Software: PC-Ord, PRIMER
Species cover and frequency	Describe the most numerically abundant species across sites in each sampling frame.	Develop ranked dominance histograms to illustrate the 20 most important species in each sampling frame. Software: Microsoft Excel, PC-Ord
Species cover and frequency (invasive species)	Describe the most important invasive species in each sampling frame.	Develop ranked dominance histograms to illustrate invasive species present in each sampling frame. Software: Microsoft Excel, PC-Ord

Analysis and Synthesis Report 2: Vegetation Composition, Structure, and Function: Interactions with Fire

This report will summarize how vegetation composition, structure, and function affect fire, and, in turn, how they are affected by fire. The subsequent Analysis and Synthesis reports on this subject every 15 years will address how vegetation and fire interrelationships are changing.

Use of the vegetation data to address fire issues was specifically requested by the parks. Fire management, which directly influences vegetation structure and composition and surface soils, is perhaps the largest potential human influence on park vegetation. In order to strengthen the analysis and focus the questions, we will work with each park and use their NPS fire monitoring data to the extent possible (although they are neither probabilistic nor floristically comprehensive or correct in all cases). We will also use data from the land cover protocol and possibly data from FIA. Use of additional data and working with park staff will enable us to address management concerns to the best degree possible with existing data.

Table 3 describes the fuel parameters, specific sub-objectives for components of this report, and the suggested analyses and software. In order to understand how existing vegetation structure will affect potential fire behavior, we will use our structure data for inputs into fire behavior modeling. Our measure of crown base height will need to be converted to canopy base height as currently used in these models. We will also use the Natural Fuels Photo (http://www.fs.fed.us/pnw/fera/research/fuels/photo_series/) to make determinations of fuel quantities and stand conditions for inputting into fire behavior models. Current models for assessing questions about vegetation and fire behavior include NEXUS (Scott and Reinhardt 2001), Behave Plus (Andrews et al. 2005). Our measure of crown base height will need to be converted to canopy base height as used in these models. We may also use the newer Crown Fire Initiation Software (Alexander 2007, Alexander et al. 2006). There will likely be more options to chose from when the analysis is performed. We may also model fire spread using software such as Farsite (Finney 2004), using ignition locations suggested by historic patterns and management expertise. Modeling outputs will include parameters such as fire intensity, rate of spread, and windspeed needed to initiate crown fire. Modeling outputs will be compared to actual fire severity and spread data to help calibrate modeling.

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Table 3. Parameters to be analyzed in Analysis and Synthesis Report 3: Structure and Function: interactions with fire.

Parameter	Vegetation Structure and Function Sub-objective	Suggested Analyses and Software
• 1 hr. fuel • 10 hr. fuel • 100 hr. fuel • 1000 hr. fuel • Litter and duff	Calculate and report quantities (metric tons/ha, tons/acre) by fuel time lag/particle size class and for litter and duff. Use to define fuel model for fire behavior modeling described below and to assess potential for soil heating during fire. Repeated measures ANOVA to analyze change over time.	Calculations using tree basal area information and species constants for specific density of wood and litter. See FMH manual (link at the bottom of the website) page 214-215) for equations. Software: Microsoft Excel, existing spreadsheets developed by the Network. SYSTAT for repeated measures ANOVA.
Shrub height in four 10 x 10 m plots.	Calculate average shrub height from four 10 x 10 m modules. Use along with canopy base height to define fuel strata gap, an input into fire behavior models. Repeated measures ANOVA to analyze change over time.	Use in fire behavior modeling. Software: as described below for modeling. SYSTAT for repeated measures ANOVA.
Fuel strata gap (Canopy base height – height of upper layer of surface vegetation).	Average canopy height based on all tree crowns in 0.1 ha plot (see Cruz et al. 2003). Use along with shrub height to define fuel strata gap, an input into fire behavior models. Repeated measures ANOVA to analyze change over time.	Use in fire behavior modeling. Suggested Software: as described below for modeling. SYSTAT for repeated measures ANOVA.
Canopy bulk density.	Use tree diameter and species to obtain canopy bulk density values based on published allometric relationships Input into fire behavior models. Repeated measures ANOVA to analyze change over time.	Use in fire behavior modeling. Software: as described below for modeling. SYSTAT for repeated measures ANOVA.
Modeled fire intensity and spread, or windspeed needed for crown fire initiation	Predict fire behavior as a function of vegetation. Changes from time 1 to time 2.	Fire behavior modeling with latest software (e.g. future versions of NEXUS (FLAMMAP), BEHAVE+, and Crown Fire Initiation Software.
Successional diversity and other vegetation conditions as affected by fire	Analyze fire history patterns and describe changes in vegetation associated with time since fire	Direct and indirect gradient analyses. Space for time substitution (chronosequence) to create time since fire gradient, along which to analyze many parameters using time series approaches. Software: PRIMER, PC-Ord, SYSTAT.

Additional analysis will focus on questions of how fire regimes are affecting vegetation. Spatial pattern analyses and chronosequence approaches will be employed for addressing these questions. The specific questions will be determined by working with park resource management staff.

Analysis and Synthesis Report 3: Vegetation Structure and Function: Wildlife Habitat

Our third Analysis and Synthesis report will focus on vegetation structure and functional attributes that most affect wildlife habitat. This was also an analysis specifically requested by park managers. However, since there are myriad wildlife that could be analyzed involving all the vegetation parameters measured under the protocol, we will work with park managers to analyze those parameters most important to particular wildlife in each park. We will also combine this report and analysis with Analysis and Synthesis Report 4 from the landbird protocol, which is scheduled the same year, to address bird-related wildlife parameters affected by vegetation in concert with bird data. We will additionally synthesize data from the land cover protocol, and combine this into a comprehensive the vegetation/wildlife/bird/habitat change Analysis and Synthesis report to meet co-occurring reporting requirements from all of these protocols. The result will be a synthetic document that addresses status and trends for wildlife habitat much more broadly than any individual protocol can. This document will be produced every 15 years, with analysis of trends becoming incorporated after the first report focusing on status.

The parameters to be measured, vegetation sub-objectives to address, and suggested analyses to examine are described in Table 4. Key wildlife parameters that will be reported from the vegetation protocol data will be canopy cover, snag and down wood amount, size and decay classes, and hardwood and shrub cover.

Table 4. Parameters to be analyzed in Analysis and Synthesis Report 3: Vegetation Structure and Function: Wildlife Habitat.

Parameter	Vegetation Structure and Function: Wildlife Sub-objective	Suggested Analyses and Software
Tree, shrub and herbaceous cover.	Describe characteristics and heterogeneity in cover types used for predicting bird and other wildlife habitat relations. Assess trend over time.	Calculate distribution, abundance, and diversity of major habitat types across each sample frame (physiognomic types). Repeated measures ANOVA for trend analyses. Software: Microsoft Access, Excel, SYSTAT
Tree basal area, abundance by size class	Describe characteristics and heterogeneity of different forest structure types used for predicting bird and other wildlife habitat relations. Assess trend over time.	Calculate distribution, abundance of forest structural types or successional stages (i.e., young, mature, and old growth) across each sample frame. Repeated measures ANOVA for trend analyses. Software: Microsoft Excel, SYSTAT
Tree height, height to canopy, canopy class	Describe characteristics and heterogeneity of tree canopy wildlife habitat features. Assess trend over time.	Calculate mean and variance in tree heights, canopy heights and canopy class in each plot and across each sample frame. Repeated measures ANOVA for trend analyses. Software: Microsoft Excel, SYSTAT
Coniferous and hardwood tree cover by vertical stratum, tree height	Describe characteristics and heterogeneity of tree functional types used for predicting wildlife habitat relations. Assess trend over time.	Graph hardwood and conifer cover by height stratum. Calculate mean and variance in tree height for each plot and across each sample frame. Repeated measures ANOVA for trend analyses. Software : Microsoft Excel, SYSTAT, SigmaPlot
Snag size, density, condition, and distribution	Describe abundance and characteristics of focal habitat elements: dead trees. Assess trend over time.	Calculate mean and variability in hardwood and conifer snag density, size, and decay class across each sample frame. Repeated measures ANOVA for trend analyses. Software: Microsoft Excel, SYSTAT, SigmaPlot
Dead and down wood volume, condition, and distribution	Describe abundance and characteristics of focal habitat elements: large diameter, down wood. Assess trend over time.	Calculate downed wood volume for hardwoods and conifers in each decay and diameter class across the sample frame. Repeated measures ANOVA for trend analyses. Software: Microsoft Excel, SYSTAT, SigmaPlot
Tree composition by canopy strata--large green trees	Describe abundance and characteristics of focal habitat elements: large trees. Assess trend over time.	Calculate density of large trees (e.g., >0.50 m). Repeated measures ANOVA for trend analyses. Software: Microsoft Excel, SYSTAT, SigmaPlot
Tree composition by canopy strata--mast producing trees	Describe abundance and characteristics of focal habitat elements: mast producing trees. Assess trend over time.	Calculate density and plot locations of large (>0.50 cm) mast-producing (oak) trees across the sample frame. Repeated measures ANOVA for trend analyses. Software: Microsoft Excel, SYSTAT, SigmaPlot, ArcGIS

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Table 4. Parameters to be analyzed in Analysis and Synthesis Report 3: Vegetation Structure and Function: Wildlife Habitat (continued).

Parameter	Vegetation Structure and Function: Wildlife Sub-objective	Suggested Analyses and Software
Browse plant height and cover	Describe abundance and characteristics of focal habitat elements: browse species. Assess trend over time.	Calculate means, variance, and plot locations of potential browse species (e.g. *Purshia*, *Salix, Populus*) in each sample frame. Repeated measures ANOVA for trend analyses. Software: Microsoft Excel, SYSTAT, SigmaPlot, ArcGIS
Riparian shrub height and shrub cover, tree cover by stratum	Describe abundance and characteristics of focal habitat elements: Riparian trees and shrubs. Assess trend over time.	Calculate mean, variance, and plot locations of focal tree and shrubs species for riparian dependent wildlife (e.g., *Salix, Populus, Alnus*, etc.). Repeated measures ANOVA for trend analyses. Software: Microsoft Excel, SYSTAT, SigmaPlot, ArcGIS

Analysis and Synthesis Report 4: Vegetation Structure and Function: Stand Dynamics

The status of reproduction and mortality, canopy dieback, wood decay classes, and other aspects of vegetation dynamics measured by the protocol will be analyzed in Report 4. The parameters and sub-objectives and suggested analyses and software are summarized in Table 5. There will also be additional functional parameters to analyze that are derived from the data collected. These include biomass/carbon, ratio of live to dead tree basal area of trees, and tree age. Tree diameter and height relationship may be used as a proxy for age in demographic analyses.

Table 5. Structural parameters to be analyzed in Analysis and Synthesis Report 4: Structure and Function-Stand Dynamics.

Parameter	Vegetation Structure Objective	Suggested Analyses and Software
Tree seedling and Sapling Abundance	Describe stand recruitment processes over time.	Develop histograms illustrating densities of juvenile tree and mature trees by height or diameter class. Software: Microsoft Excel, SigmaPlot, SYSTAT
Snag density by decay class	Describe tree mortality and decay processes over time.	Calculate densities of snags in each decay class as a proxy for time since tree death. Software Platforms: Microsoft Excel, SYSTAT
Tree canopy condition	Describe factors affecting tree and canopy health and potential trends over time.	Calculate mean, variance, and spatial distribution of canopy mortality. Software: Microsoft Excel,SYSTAT, ArcGIS
Tree cover by height stratum	Describe patterns of canopy succession and dominance and potential trends over time.	Calculate the distributions of tree species by height stratum to canopy dominance in different strata. Software: Microsoft Excel, SigmaPlot, SYSTAT
Disturbance presence and type	Describe natural and anthropogenic disturbance processes and potential trends over time.	Calculate the types, abundance, and distribution of vegetation disturbances in each sampling frame. Use landcover data or analyses to supplement plot data. Suggested Software Platforms: Microsoft Excel, SigmaPlot, SYSTAT
Tree basal area	Describe tree dominance and stand biomass over time.	Calculate the mean, variance in stand biomass, plot spatial pattern. Software: Microsoft Excel, SigmaPlot, SYSTAT

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Analysis and Synthesis Report 5: Analysis of Vegetation Trends in the Network after 15 Years

The fifth Analysis and Synthesis report will present the first trend assessment. In year 15, we will have visited each park five times and we expect to have a sufficient time series to begin the detection of vegetation trends that are occurring at a relatively rapid pace. Determination of significant trends in vital signs will require considerably more time than status, depending on the degree of variance and magnitude of change in each vital sign.

Trends will be analyzed for vegetation composition and structural and functional parameters described in Tables 2-5. Table 6 describes the parameters, sub-objectives for analyses of vegetation trends, and suggested software and analyses.

Table 6. Trend analyses to be undertaken in Analysis and Synthesis Report 5.

Parameter	Trend Sub-objectives	Suggested Analyses and Software
Vegetation Composition		
Species presence and abundance (cumulative in 0.1 ha plot)	Detect ecologically significant changes in species composition if they occur	Permanova[1], rank correlation to determine significance of relationship between composition distance (Bray-Curtis distance measure) and time. Control chart analysis to determine abnormal levels or rates of change in composition. Software: 'R,'SYSTAT
Relative abundance (herbaceous and shrub cover, tree basal area) of 20 most dominant species in each sample frame as well as invasive species	Detect ecologically significant changes in relative abundance of dominant species if they occur	Parametric and nonparametric time series analysis of species relative abundance. Control chart analysis and rank clocks to determine rates of change in dominance. Software: 'R,'SYSTAT
Species richness and derived diversity metrics (evenness, Pielou's J, Fisher's α)	Detect ecologically significant changes in species richness if they occur	Parametric and nonparametric time series analysis of species diversity. Plot "hot spots" of change in each sampling frame. Species area curves. Software: 'R,'SYSTAT, ArcGIS
Structure and Function: Fuels and Potential Fire		
Fuel beds (down wood, litter, duff)	Detect ecologically significant changes in ground fuels should they occur	Parametric and nonparametric time series analysis of quantities and depth per ha. Plot "hot spots" of change in each sampling frame. Software: 'R,'SYSTAT, ArcGIS
Live fuels (shrub height, canopy base height, canopy bulk density)	Detect ecologically significant changes in live fuels should they occur	Parametric and nonparametric time series analysis of changes in average canopy base height and density. Plot "hot spots" of change in each sampling frame. Software Platforms: 'R,'SYSTAT, ArcGIS
Fire behavior modeling outputs (fire intensity, rate of spread, windspeed needed for crown fire)	Detect ecologically significant changes in potential fire behavior should they occur.	Parametric and nonparametric time series analysis of modeling outputs. Plot "hot spots" of change in each sampling frame. Software Platforms: 'R,'SYSTAT, ArcGIS
Structure and Function: Wildlife		
Snag density	Detect ecologically significant changes in snag density should they occur.	Parametric and nonparametric time series analysis of snag density. Plot "hot spots" of change in each sampling frame. Software: 'R,'SYSTAT, ArcGIS

Table 6. Trend analyses to be undertaken in Analysis and Synthesis Report 5 (continued).

Parameter	Trend Sub-objectives	Suggested Analyses and Software
Down wood	Detect ecologically significant changes in down wood should they occur	Parametric and nonparametric time series analysis of down wood volume, size and decay classes. Plot “hot spots” of change in each sampling frame. Software: ‘R,’SYSTAT, ArcGIS
Large green tree density	Detect ecologically significant changes in large green tree density should they occur	Parametric and nonparametric time series analysis of large snag density. Plot “hot spots” of change in each sampling frame. Software: ‘R,’SYSTAT, ArcGIS
Structure and Function: Stand Dynamics		
Seedling and Sapling Density	Detect ecologically significant changes in recruitment should they occur.	Parametric and nonparametric time series analysis of tree recruitment. Identify high and low recruitment years by location. Plot “hot spots” of change in each sampling frame. Software: ‘R,’SYSTAT, ArcGIS
Snag Density by Decay Class	Detect ecologically significant changes in snag density should they occur.	Parametric and nonparametric time series analysis of snag recruitment and decrease (fall rate). Identify high and low recruitment years by location. Plot “hot spots” of change in each sampling frame. Software: ‘R,’SYSTAT, ArcGIS
Disturbances	Describe disturbance patterns, events	Because of the episodic nature of disturbance and the long-term nature of most disturbance regimes, it is unlikely that we will be able to detect trends or determine abnormality in this parameter over 15 years. However, general statistical summaries and descriptive mapping of disturbances should be prepared, as appropriate, to illustrate important dynamics over the time period. Software: Excel, SigmaPlot, SYSTAT, ArcGIS
Tree Basal Area	Detect ecologically significant changes in tree basal area should they occur.	Parametric and nonparametric time series analysis of tree recruitment. Identify high and low recruitment years by location. Plot “hot spots” of change in each sampling frame. Software: ‘R,’SYSTAT, ArcGIS

*Environmental variables: Elevation, slope, aspect, microtopography, macroposition, disturbance, derived GIS topographic or moisture variables or time since fire.
[1]Permutational Multivariate Analysis of Variance (non-parametric)

After the fifth Analysis and Synthesis report, we will begin the same reporting cycle again, unless it has been modified along the way.

Multivariate Analyses and Detection of Trend

Much of the information and insight about temporal change will be contained in multivariate analyses of vegetation composition data in relation to environmental parameters. These analyses can be used to efficiently explore the data and identify progressive changes (Figure 1). This is based on assessing cumulative plot dissimilarity over time, and in the context of outlier determination and control chart development (McBean and Rovers 1998, Anderson and Thompson 2004) (Figure 2). Compositional changes can provide compelling evidence that a meaningful ecological event has occurred, or an ecological threshold has been exceeded (Anderson and Thompson 2004). At a minimum, cumulative dissimilarity ordinations (Figures 1 and 2) will be developed for each sampling frame from each park (total = 14) for the first 15 years of the program.

Philippi et al. (1998) suggest tests for trend in matrices of similarity indices derived from multi-date species data: 1. Non-parametric multivariate analysis of variance can be used with a matrix of dissimilarities which can be partitioned into residual sums of squares to test for trend from the baseline condition (time 1, or another time period or reference). Significance is determined through a randomization test of date labels. 2. Mantel test of a locational dissimilarity matrix to the temporal time difference matrix. Randomization following the traditional Mantel test then tests for significance of association between time and species composition (Manly 1997).

Other tests for progressive trend in assemblage data exist, such as the canonical analysis of principal coordinates (CAP) as proposed by Anderson and Willis (2003) and Anderson and Robinson (2003), and the perMANOVA test. The CAP analysis can be implemented in the R software vegan package with the capscale() function, or in the PRIMER software (PERMANOVA for PRIMER). Also, perMANOVA could be used to test for differences amongst sampling periods, amongst sites, and the error term would be the site by sampling period interaction (Anderson 2001). This can be implemented in the vegan package as well with the adonis() function; this is another permutation approach so computational time is high and the number of iterations used may have to be adjusted.

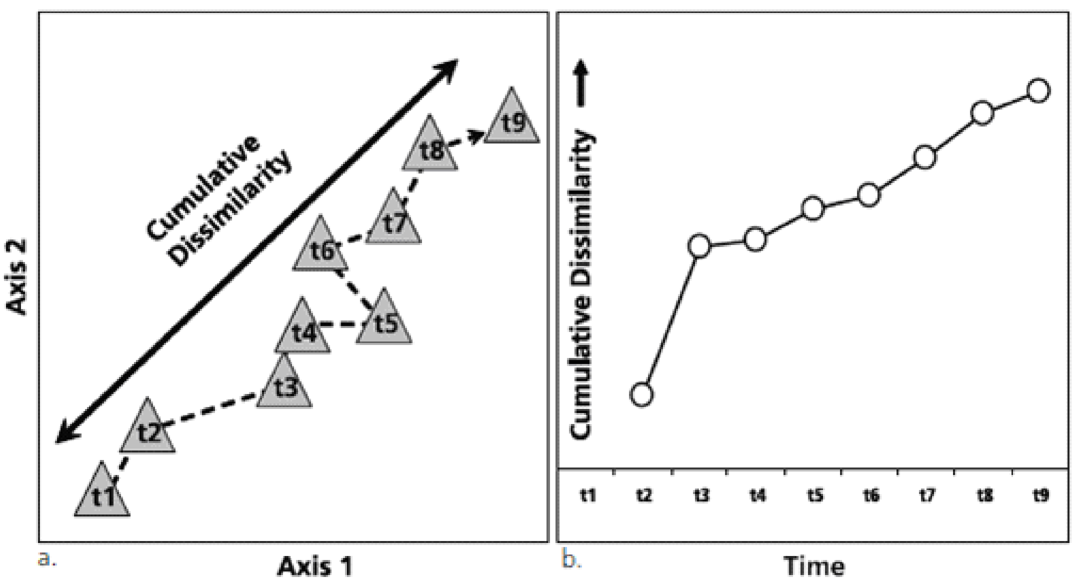

Figure 1. Cumulative change in species composition over nine sampling seasons. a.) An idealized two-dimensional ordination diagram illustrating the compositional position of a site at time one through nine, where Euclidean distance between each year (i.e., time steps t1, t2...t9) is proportional to species dissimilarity. The solid two-headed arrow is an ordination that illustrates the cumulative dissimilarity (progressive compositional change) over the whole period. b.) A graph of cumulative dissimilarity between the first year sample and successive years (i.e., t1 to tn). Note that the change is positive and sustained, suggesting a clear trend of changing composition over time.

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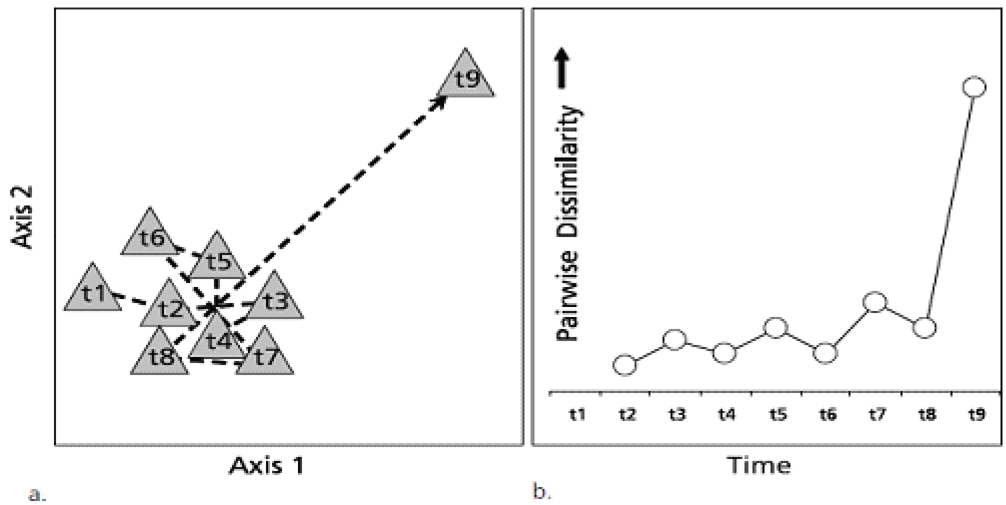

Figure 2 a and b. Year-to-year change in species composition over nine sampling seasons, with a major change at year nine. a.) An idealized two-dimensional ordination diagram illustrating the compositional position of a site at time one through nine where Euclidean distances between each pair of years (i.e., time steps t1, t2...t9) are proportional to pairwise species dissimilarity. The dashed arrow follows the year-to-year change in composition. b.) A graph of pairwise dissimilarity between each pair of successive time steps from years one to nine. Note that the composition is similar, but slightly variable in years one to eight, with a major change in year nine.

We provide an example that displays a strong progressive trend based on the data in Sarr and Hibbs (2007). These data were gathered across a strong environmental spatial gradient, but we make the assumption that such a gradient could occur across time under a scenario of accelerated climate change. We notice a strong pattern in both the visualization of the data through plots and ordinations as well as using the Mantel test for progressive trend. This multi-faceted approach to data analysis is beneficial because managers are more likely to understand graphical displays than simply a p-value when describing vegetation assemblages changing over time.

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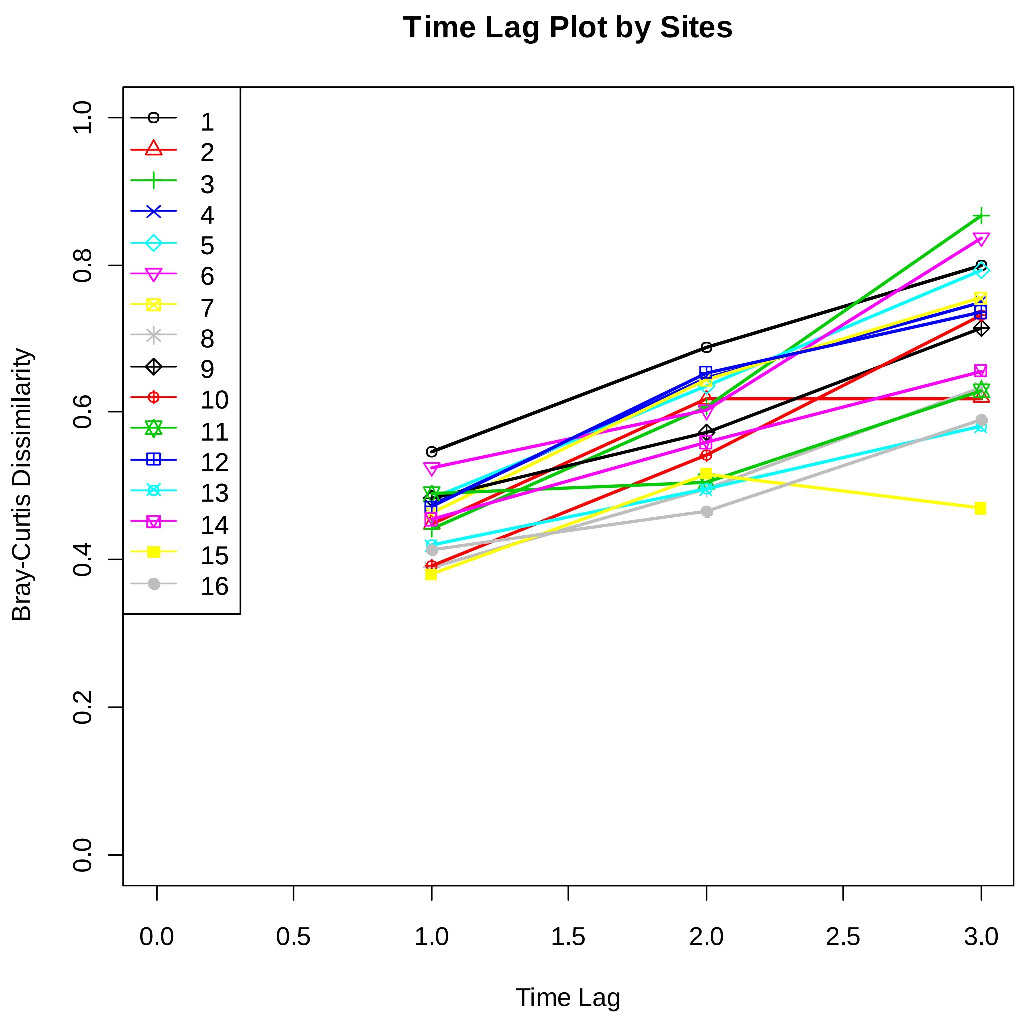

Figure 3. Time lag plot of the mean dissimilarity for each site. The mean is the average dissimilarity at each lag class for each site. This plot shows a strong progressive trend across the 16 sites through time.

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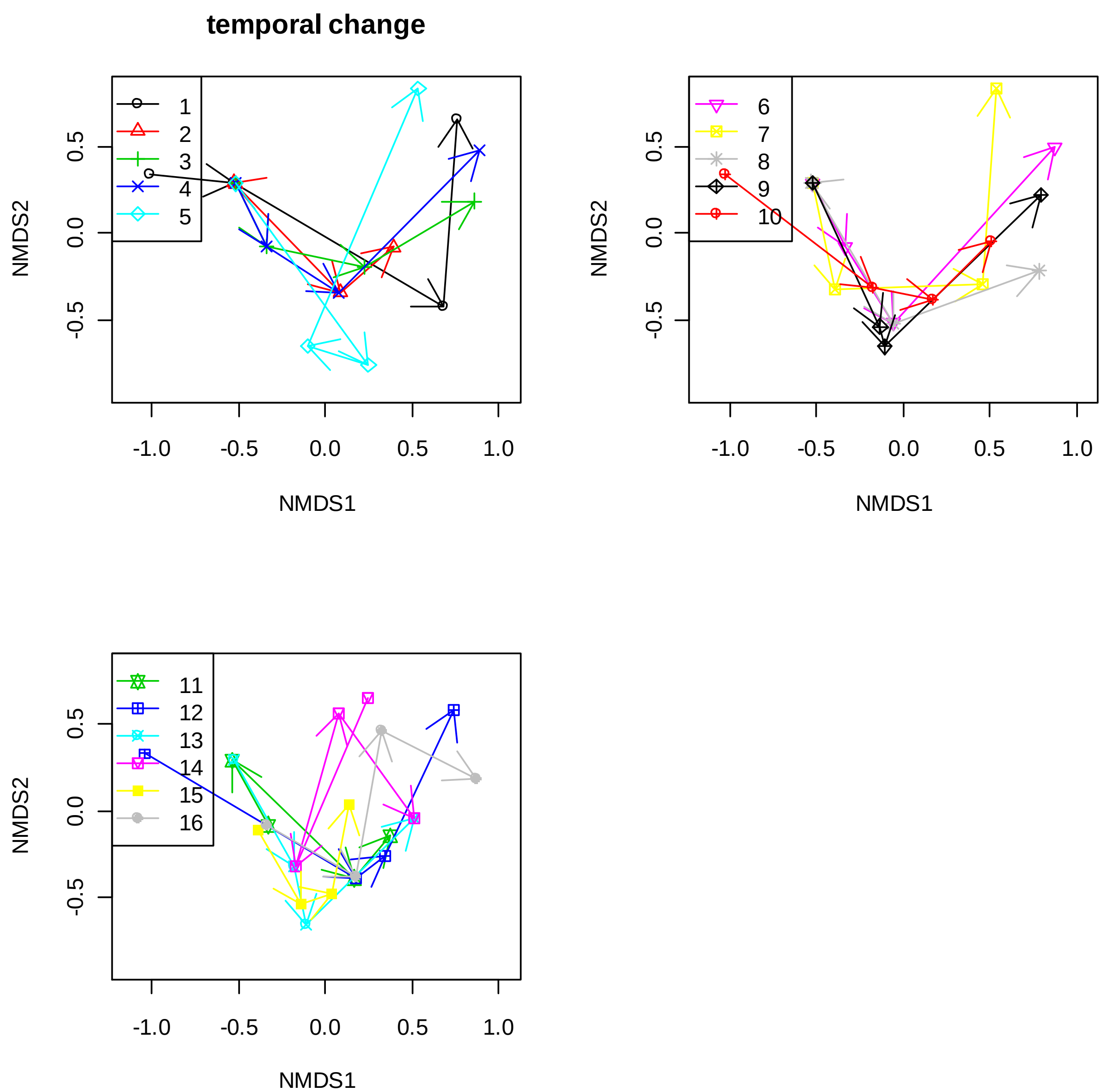

Figure 4. The bi-plot using the first and second axis of Nonmetric Multi-Dimensional Scaling (NMDS) ordination. The observations are colored according to the unique sites sampled over time. The arrows connect the site observations over time. There is a strong pattern with arrows tracking along NMDS1, consistent with theoretical display in Figure 1.

The easiest test to implement for progressive trend is the Mantel test (see McCune and Grace 2002, Chapter 27). We provide an example here that requires some understanding of multivariate statistics and the R software.

In the Mantel test for progressive trend, two distance matrices need to be created, one for the response and one for the explanatory variable (time). The response variable is the vector of dissimilarity values, or the upper triangle (i.e., nonzero values) of the dissimilarity (resemblance) matrix http://www.statistics.com/resources/glossary/d/dissimmatr.php calculated from the raw site by species matrix. Calculation of the dissimilarity matrix using R is specified at http://cc.oulu.fi/~jarioksa/softhelp/vegan/html/vegdist.html. The explanatory variable for progressive trend is time. For the vegetation protocol, this will be sample periods spaced 3 years apart (1, 4, 7 years and so on). The Mantel test for progressive trend is just the correlation between the response and explanatory variable. Figure 5 displays the example data used to calculate the spearman correlation between Bray-Curtis dissimilarity and the time lag. The Mantel test is implemented within the R package vegan, http://cc.oulu.fi/~jarioksa/softhelp/vegan/html/mantel.html. The observed data produce a Spearman correlation statistic of 0.60. To assess the significance of this value, a permutation distribution is found by randomly assigning a dissimilarity value to one of the time lags within a site; e.g., time lag 1 might now become time lag 3. For each permutation of the dissimilarity values, the Spearman correlation is calculated again. To calculate the p-value, the number of values equal to or more extreme than the observed 0.599 are counted and divided by the total number of permutations. The permutations are constrained within a site because we have fixed sites for sampling. In vegan using the Mantel function, the strata argument should equal the variable containing the site unique identifier. One should also be aware that as implemented in vegan, the p-value is assuming the one-sided test for a positive correlation. The implementation in vegan is based on that described in Legendre and Legendre (1998). The Mantel test can be done in PRIMER using the RELATE function.

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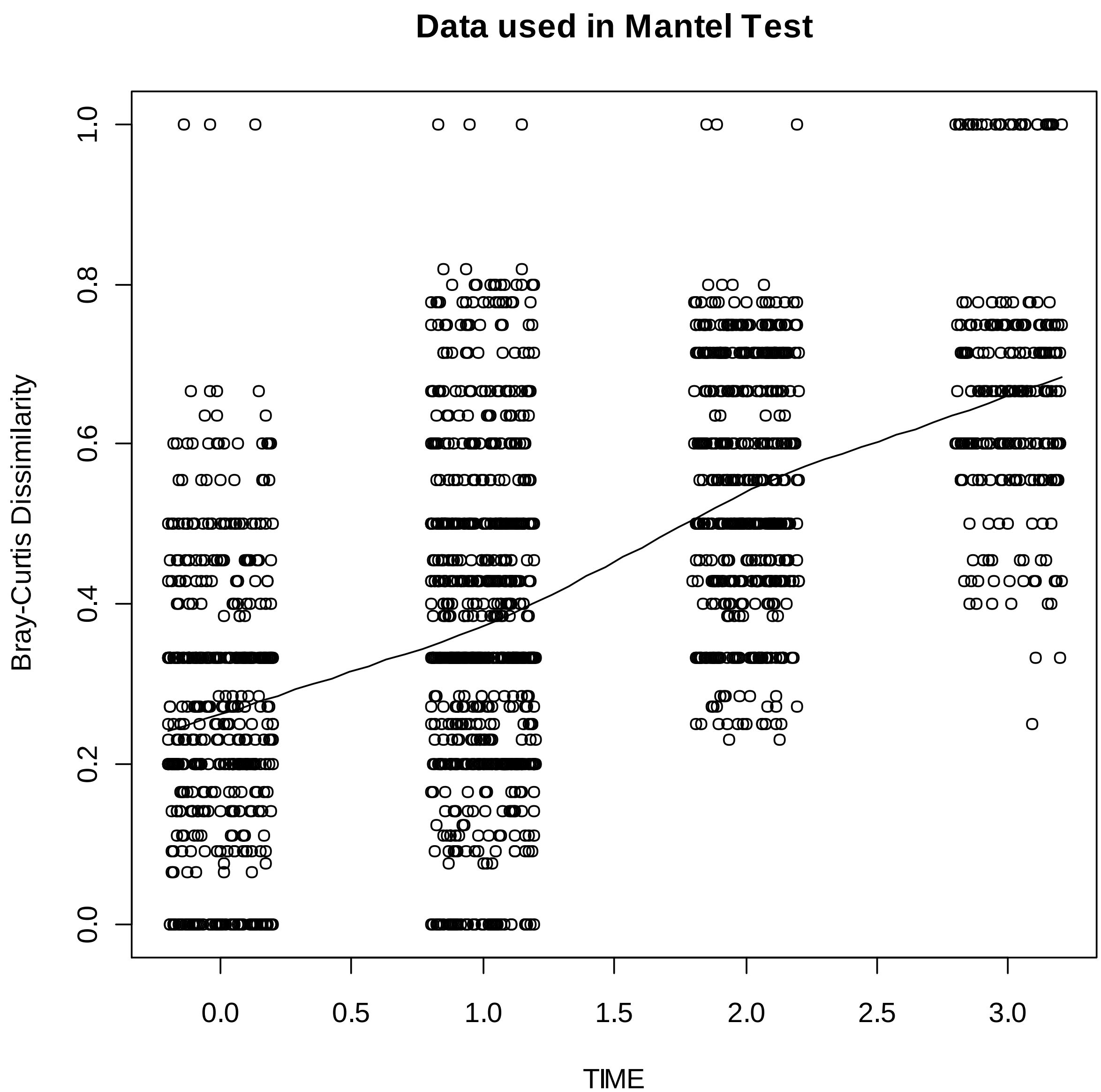

Figure 5. Data used in the Mantel test with a smoother added to aid in visualizing a trend in the dissimilarity values over time. In the Mantel test, permutations are constrained within a site. There is a strong trend which corresponds to the large Mantel statistic values of 0.599.

Based on the Mantel test for progressive trend, there is strong evidence of progressive trend in the woody species assemblage dissimilarities (constrained permutation p-value < 0.001) in the Sarr and Hibbs (2007) data. The estimated magnitude of the Mantel statistic is large (0.60). Others have investigated the connection between the Mantel statistic and the Pearson correlation coefficient (Dutilleul et al. 2000, Goslee 2010). One should be aware that a significant p-value can occur for a very low Mantel statistic, although this is not the case for these data.

Multivariate outputs will suggest many specific analysis possibilities for the large number of univariate parameters beyond those outlined in Table 6. Targeted analyses and statistical methods will be chosen based upon outstanding research or management questions in each park.

General tools for the determination of trend in univariate parameters will range in complexity from application of general linear models (Manly 2001), to time series analyses of longer-term datasets for univariate parameters (Box and Jenkins 1976, Manly 2001), analyses of covariance (ANCOVA), and non-parametric procedures. Regression-based analyses for trend detection (e.g., F-test of slope) should account for the year, interaction, and residual sources of variation.

For the sample panel with 3 year revisits, a regression model (linear model) can be used to analyze change over time in univariate parameters such as shrub height, seedling density, or basal area that are continuous variables. The basic model for trend is: $\log(Y_{ij}) = \beta_{0j} + \beta_{1j} Yr_i$ where Y_{ij} is the observed characteristic of interest (e.g., shrub height) for site *j* in year *i*. This model assumes site-specific trends over time. This model is a “rich” model in terms of modeling the fixed sites over time, separate lines for each site j ($\beta_{oj} + \beta_{1j}$). However, the linear assumption of trend through time should be evaluated based on data. Also, this model can be compared to reduced models of parallel lines ($\beta_{1j} = \beta_1$ for all *j*), or a common line ($\beta_{oj} = \beta_0$ for all *j* and $\beta_{1j} = \beta_1$ for all *j*). On the back-transformed scale, the trend is in terms of a multiplicative change in the medians over time [$\exp(\beta_1)$]; this is typically appropriate for biological data that display exponential growth and increasing variability with an increase in mean. This model assumes that the residuals have constant variance, are independent, and follow a normal distribution. These assumptions should be verified through standard visual displays, residual plots, and qqplots. For variables that do not meet these assumptions, Generalized Linear Models (GLMs) could be used which allow for alternative error distributions appropriate for counts, proportions, or ordered categories (e.g., Agresti 2002). The SYSTAT software has a flexible dialog box for hypothesis testing with GLMs. This includes an option for post-hoc analyses for repeated measures.

New techniques are also emerging that allow complex dynamics of species dominance shifts to be more clearly demonstrated, for example, rank abundance clocks (Collins et al. 2008). Rank abundance analyses may be undertaken to complement ordination analyses for each sampling frame. As new methods evolve, this SOP will need to be revised accordingly.

Assessing Change

The National Park Service goal of maintaining unimpaired conditions has traditionally been interpreted to mean that conditions remain stable and unaffected by humans. Unfortunately, there are no benchmarks that provide an unambiguous measure of when conditions are becoming “unimpaired” (Cole et al. 2008). All ecosystems are dynamic, characterized by natural disturbance regimes (Pickett and White 1985, Wu and Loucks 1995, Poff et al. 1997) and long-term fluctuations in climate and biogeography (see Whitlock and Bartlein 1997, Mohr et al. 2000, Weisberg and Swanson 2003, and Whitlock et al. 2008 for analyses from the Klamath Region). Relatively infrequent, extreme events are important parts of the disturbance regime in most natural ecosystems (Benda and Dunne 1997, Moritz 1997). Disturbance-mediated variation is important for vegetation diversity (Odion and Sarr 2007), yet the dynamics are often highly nonlinear and vary with scale (Sarr et al. 2005), making them difficult to place into the context of "unimpaired."

With paleoecological, fire history, and archaeological studies, we are only now coming to an understanding of some of these natural dynamics in park landscapes. Our limited understanding is compounded by the fact that parks are not, as once assumed, insulated from human impacts like climate change and altered fire regimes. There have also been human-caused declines and extirpations in keystone species such as top terrestrial predators, including wolves and grizzly bears. Ecosystem engineers such as beavers may be much less common today. These cumulative human impacts may have considerably altered our ability to assess baseline vegetation conditions. We will need to develop a quantitative understanding of what is acceptable variation in ecosystems for which there are no historical analogs. This may be one of the most challenging analysis problems the National Park Service faces (Cole et al. 2008).

We will explore indices of biological or ecological integrity (IBIs, IEIs; Karr and Chu 1999) to help differentiate acceptable from unacceptable change. These indices are based on the approach of using reference sites unimpacted by particular human stressors against which potentially affected areas are compared. Reference sites can be plots that happen to fall into unimpacted areas. There are no perfect reference sites, but there are sites that may be lacking particular human impacts such as invasive species, predator removal, fire suppression, and stream flow alteration. Although indices of biological integrity have been most successfully applied in aquatic ecosystems, where disturbance or pollution effects have been well studied (Karr 1991), they more recently have been developed and applied in riparian and wetland environments (Innis et al. 2000) for terrestrial invertebrates (Kimberling et al. 2001) and for bird communities (O'Connell et al. 2000). The indices may rely on a variety of taxa, and we expect to evaluate biotic integrity using data not only from the vegetation protocol, but also from the landbird (which has co-located monitoring sites), invasive species, land cover, water quality, whitebark pine, and cave protocols (the cave protocol will be monitoring vegetation and wildlife at cave entrances). We expect that indices of biotic integrity may prove valuable in interpreting the acceptability of vegetation change and identifying where management intervention can mitigate unacceptable change.

Report Format

Annual reports and third year Analysis and Synthesis reports will use the NPS Natural Resource Publications template, a pre-formatted Microsoft Word template document based on current NPS formatting. Annual reports and third year Analysis and Synthesis reports will be formatted using the Natural Resource Technical Report template (http://www.nature.nps.gov/publications/NRPM/NRTR.dot). These templates and documentation of the NPS publication standards are available at: http://www.nature.nps.gov/publications/NRPM/index.cfm.

SOP #12: Reporting and Analysis of Data (continued).

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